

REMARKS

Reconsideration and allowance of the above-referenced application are respectfully requested.

Enclosed with this amendment is a substitute specification.

Entry of the amendments to the claims prior to initial examination is requested. Applicant believes that no fee is due.

Attached is a marked-up version of the changes being made to the claims by the current preliminary amendment.

Please apply any charges or credits to Deposit Account No. 06-1050.

Respectfully submitted,

Date: \_\_\_\_\_

5/1/02



\_\_\_\_\_  
Scott C. Harris  
Reg. No. 32,030

SCH/smr

Fish & Richardson P.C.  
PTO Customer No. 20985  
4350 La Jolla Village Drive, Suite 500  
San Diego, California 92122  
Telephone: (858) 678-5070  
Facsimile: (858) 678-5099

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VERSION TO SHOW CHANGES MADE

In the Specification:

Enclosed with this amendment is a substitute specification provided as a marked-up copy to be placed in the file.

In the Claims:

The claims have been amended as follows.

3. The method of claim 2, wherein said determining the status of the re-routing bridge in the bus interface [is enabled] comprises checking a status of a bridge-enable bit in a control register.

8. Apparatus comprising:  
a processor core including  
a [local] memory including a local data memory and a local instruction memory,  
a first port coupled to the local data memory, and  
a second port coupled to the local data memory and the local instruction memory; and  
a bus interface including  
a first bus coupled to the first port,  
a second bus coupled to the second port,  
a bridge between the first bus and the second bus, and

a multiplexing unit operative to switch between the second bus and the bridge to enable information placed onto the first bus to be re-routed into the second port.

15. An article comprising a machine-readable medium including machine-executable instructions, the instructions operative to cause:

a machine to route a memory access from a processor core back into the processor core through a bus interface coupled to the processor core.

22. A system comprising:

a processor comprising

[a processor core including]

a local memory including a local data memory and a local instruction memory,

a first port coupled to the local data memory, and

a second port coupled to the local data memory and the local instruction memory; and

a bus interface including

a first bus coupled to the first port,

a second bus coupled to the second port,

a bridge between the first bus and the second bus, and

a multiplexing unit operative to switch between the second bus and the bridge to enable information placed onto the first bus to be re-routed into the second port; and

a USB (Universal Serial Bus) interface[; and

a system bus coupled to the processor and the USB interface].

23. The system of claim 22, wherein the local memory has an address space, and further [comprising] comprises a bus control unit operative to switch the multiplexer to the bridge in response to a bridge-enable flag being set and an address of a memory location associated with a memory access from the processor core falls within the local memory address space.

New claims 29-32 have been added.



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Sub SPEC  
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# **METHOD AND APPARATUS FOR CONVERTING AN EXTERNAL MEMORY ACCESS INTO A LOCAL MEMORY ACCESS IN A PROCESSOR CORE**

## **BACKGROUND**

[0001] Memory in a computer system may be arranged in a memory hierarchy including memories of different speeds and sizes. The type and size of a memory device and its proximity to the processor core are factors in the speed of the memory device. Generally smaller hardware is faster, and memory devices closest to the processor core are accessed fastest. Since fast memory may be expensive and space near the processor core limited, a memory hierarchy may be organized into several levels, each smaller, faster, and more expensive per byte than the next level. The goal of such a memory hierarchy is to provide a memory system with a cost almost as low as the cheapest level of memory and speed almost as fast as the fastest level.

[0002] Many processors store copies of the most used data and instructions in a memory cache to improve access speed and overall processing speed. A memory cache, also referred to as cache store or RAM (Random Access Memory) cache, is a portion of memory which may be made of high-speed static RAM (SRAM) instead of the slower dynamic RAM (DRAM) typically used for main memory. Memory caches may

be included on the same integrated circuit (IC) as the processor. Such internal memory caches are also referred to as local or Level 1 (L1) caches.

**[0003]** The contents of the L1 cache may change depending on the task being performed by the processor. If the processor tries to access data that is not in the cache, a cache miss occurs, and the data is retrieved from memory. Cache misses involve a performance penalty which includes the clock cycle in which the miss occurred and the additional clock cycles to service the miss. Accordingly, it may be desirable to provide a local memory, e.g., an L1 SRAM, to store data and instructions to improve access speed and reduce cache miss penalties.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0004]** Figure 1 is a system including a processor core and system bus interface (SBI) according to an embodiment.

**[0005]** Figure 2 is a flowchart describing an operation for enabling a processor core to write to a local instruction memory according to an embodiment.

**[0006]** Figure 3 is a system including a processor according to an embodiment.

**DETAILED DESCRIPTION**

**[0007]** Figure 1 illustrates a system 100 according to an embodiment. The system includes a processor 102 with a processor core 105, which interprets and executes instructions. The processor core 105 may access data from an external memory 110, e.g., a Level 2 (L2) or main memory, via a system interface bus (SBI) 115. The processor 102 may be, for example, a microcontroller or a digital signal processor (DSP), which are typically used for controller-oriented applications and numerically intensive digital signal processing, respectively. The processor 102 may have a hybrid microcontroller/DSP architecture which is able to handle applications which have both DSP- and microcontroller-based components. Such a processor may be used in, for example, a cellular phone which has a workload with a large DSP component for performing the processing required for the base-band channel and the speech codes, as well as a control-oriented component for managing aspects of the user interface and communication protocol stacks.

**[0008]** The processor core 105 may include a local, or Level 1 (L1), memory at the highest level of the memory hierarchy. The instructions and data in the L1 memory may be separated into a local instruction memory 120 and a



local data memory 125, but may share a common memory at the second and further levels of the system (L2 and lower).

The separation of the instruction and data streams may enable the processor core 105 to simultaneously fetch instructions and load/store data without collisions.

**[0009]** The local memories may include caches that store copies of the most used data for fast retrieval by an execution unit 130. The information in the cache may be deterministic, i.e., may change depending on the tasks being performed by the processor. A cache miss may occur when the processor core 105 tries to access data that is not in the local cache. In the event of a cache miss, the requested data that is not in the local cache may be retrieved from the external memory 110. The data retrieved due to a cache miss may be transferred to the cache from the external memory via a fill bus 135. A cache miss may involve a penalty which includes the clock cycle in which the miss occurred and the additional clock cycles to service the miss.

**[0010]** In addition to, or in place of, the L1 cache, the processor core 105 may include local (real) memory which may be programmed with information, such as L1 SRAM in the local instruction memory 120 and the local data memory 125. Unlike the L1 cache, the information in the L1 SRAM may be

addressable and does not depend on the task being performed, i.e., the information in the L1 SRAM is non-deterministic. Thus, accesses to L1 SRAM may not entail cache miss penalties. Due to its proximity to the execution unit 130, the L1 SRAM may be a relatively fast memory and may be used to store instructions and data for DSP applications, such as fast Fourier processing (FFP), correlation, and multiply-accumulate (MAC) instructions.

**[0011]** The execution unit 130 may read and write data to the local data memory 125 during execution of a program. The execution unit 130 may fetch instructions from the local instruction memory 120, but may not be able to write directly to the local instruction memory 120.

**[0012]** The system 100 may include a DMA (Direct Memory Access) controller 140. The DMA controller 140 is a specialized processor used to transfer information in or out of the local instruction memory 120 and local data memory 125 without intervention by the processor core 105. The DMA controller 140 may be external to the processor core 105 and accesses local memory through the SBI 115. The DMA controller may read and write instructions to the local instruction memory 120 and read and write data to the local data memory 125.

**[0013]** The SBI 115 includes the fill bus 135 and the DMA bus 145. A fill bus interface 148 handles data transfers between the external memory 110 and a system port 150. A DMA bus interface 155 handles data transfers between the DMA controller 140 and a system DMA port 160. The processor core 105 may include an internal DMA interface 165 to handle transfers between the system DMA port 160 and the local memories 120 and 125.

**[0014]** The SBI 115 may operate in a normal operating mode and an enhanced operating mode. In the normal operating mode, the local instruction memory 120 may not be written to directly by the processor core 105, but may be written to by the DMA controller 140. In the enhanced operating mode, the SBI 115 may re-route data on the system port 150 to the system DMA port 160 via a bridge 170 in the SBI 115 which connects the fill bus 135 and the DMA bus 145. The processor core 105 may use the bridge 170 to write directly to the local instruction memory 120.

**[0015]** A multiplexer 175 may be provided on the DMA bus 145. The bridge 170 may route data placed on the fill bus 155 by the system port 145 to the multiplexer 175. In the normal operating mode, the multiplexer may close the bridge and allow instructions and data to flow between the system DMA port 160 and the DMA bus interface 155. In the

enhanced operating mode, the multiplexer may switch to the bridge 170 and allow instructions and data to flow between the system port 150 and the system DMA port 160.

**[0016]** The multiplexer 175 may be controlled by the output of an AND gate 180. The inputs of the AND gate 180 may be coupled to a control register 185 and an address decoder 190, respectively. The control register 185 may be a software programmable register which may be programmed to store a bridge-enable bit. The bridge-enable bit may be used to indicate whether the bridge is enabled or not, and hence whether the SBI 115 is in the normal or enhanced operation mode.

**[0017]** Figure 2 is a flowchart describing an operation 200 for enabling the processor core 105 to write the local instruction memory 120 and the local data memory 125 according to an embodiment, although the scope of the present invention is not limited in this respect. The processor core 105 may request an access to memory, e.g., a read or write access to the local instruction memory 120 (block 202). The SBI 115 receives the access request (block 204) and checks the status of the bridge-enable bit in the control register 185 (block 206). If the bridge-enable status is FALSE, i.e., the bridge-enable bit value is zero, the processor 102 may be in the normal operating

mode, and the output of the AND gate 180 is FALSE. The multiplexer 175 blocks the information on the bridge 170 from being placed on the DMA bus 145, and the access request is sent to the external memory 110 (block 208).

**[0018]** The SBI 115 may also check the address of the target instruction or data with the address decoder 190 to determine if the address of the target to be accessed is within the address space assigned to the local memories 120 or 125 (block 210). If not, the output of the address decoder 140 is FALSE. Consequently, the output of the AND gate 180 is FALSE, and the access request may be sent to the external memory 110 (block 208).

**[0019]** If the bridge-enable status is TRUE, i.e., the bridge-enable bit value may be one, and the address of the target may be in the local memory address space, then the output of the AND gate is TRUE. The multiplexer 175 may switch to the bridge 175 and places the access request on the DMA bus 145 going back to the processor core 105 (block 212). If the access request is a write to the local instruction memory 120, the internal DMA interface 165 writes the information to the appropriate address in the memory 120 (block 214).

**[0020]** The enhanced mode may be used for testing purposes. For example, if a test chip on which a processor

under development does not include a DMA controller, the processor core 105 may be used to test the internal logic of the DMA bus interface in the SBI 115. The enhanced mode may also be used to insert breakpoints in the code in the local instruction memory 120 using the processor core 105. The breakpoints may be used to test different portions and functions of the code. The enhanced mode may also be used for development purposes, such as code patching to replace portions of code in the local instruction memory 120 using the processor core 105.

**[0021]** The processor 102 may be implemented in a variety of systems including general purpose computing systems, digital processing systems, laptop computers, personal digital assistants (PDAs) and cellular phones. In such a system, the processor may be coupled to a memory device, such as a Flash memory device or a static random access memory (SRAM), which stores an operating system or other software applications.

**[0022]** Such a processor 102 may be used in video camcorders, teleconferencing, PC video cards, and High-Definition Television (HDTV). In addition, the processor 102 may be used in connection with other technologies utilizing digital signal processing such as voice

processing used in mobile telephony, speech recognition, and other applications.

**[0023]** For example, Figure 3 illustrates a mobile video device 300 including a processor 102 according to an embodiment. The mobile video device 300 may be a hand-held device which displays video images produced from an encoded video signal received from an antenna 302 or a digital video storage medium 304, e.g., a digital video disc (DVD) or a memory card. The processor 102 may communicate with an L2 SRAM 306, which may store instructions and data for the processor operations, and other devices, for example, a USB (Universal Serial Bus) interface 308.

**[0024]** The processor 102 may perform various operations on the encoded video signal, including, for example, analog-to-digital conversion, demodulation, filtering, data recovery, and decoding. The processor 100 may decode the compressed digital video signal according to one of various digital video compression standards such as the MPEG-family of standards and the H.263 standard. The decoded video signal may then be input to a display driver 310 to produce the video image on a display 312.

**[0025]** A number of embodiments have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit

and scope of the invention. For example, blocks in the flowchart may be skipped or performed out of order and still provide desirable results. Accordingly, other embodiments are within the scope of the following claims.





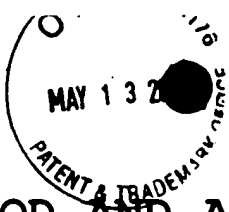
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# METHOD AND APPARATUS FOR CONVERTING AN EXTERNAL MEMORY ACCESS INTO A LOCAL MEMORY ACCESS IN A PROCESSOR CORE

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## BACKGROUND

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[0001] Memory in a computer system may be arranged in a memory hierarchy including memories of different speeds and sizes. The type and size of a memory device and its proximity to the processor core are factors in the speed of the memory device. Generally smaller hardware is faster, and memory devices closest to the processor core are accessed fastest. Since fast memory may be expensive and space near the processor core limited, a memory hierarchy may be organized into several levels, each smaller, faster, and more expensive per byte than the next level. The goal of such a memory hierarchy is to provide a memory system with a cost almost as low as the cheapest level of memory and speed almost as fast as the fastest level.

[0002] Many processors store copies of the most used data and instructions in a memory cache to improve access speed and overall processing speed. A memory cache, also referred to as cache store or RAM (Random Access Memory) cache, is a portion of memory which may be made of high-speed static RAM (SRAM) instead of the slower dynamic RAM (DRAM) typically used for main memory. Memory caches may

be included on the same integrated circuit (IC) as the processor. Such internal memory caches are also referred to as local or Level 1 (L1) caches.

**[0003]** The contents of the L1 cache may change depending on the task being performed by the processor. If the processor tries to access data that is not in the cache, a cache miss occurs, and the data is retrieved from memory. Cache misses involve a performance penalty which includes the clock cycle in which the miss occurred and the additional clock cycles to service the miss. Accordingly, it may be desirable to provide a local memory, e.g., an L1 SRAM, to store data and instructions to improve access speed and reduce cache miss penalties.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0004]** Figure 1 is a system including a processor core and system bus interface (SBI) according to an embodiment.

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[0007] Figure 1 illustrates a system 100 according to an embodiment. The system includes a processor 102 with a processor core 105, which interprets and executes instructions. The processor core 105 may access data from an external memory 110, e.g., a Level 2 (L2) or main memory, via a system interface bus (SBI) 115. The processor 102 may be, for example, a microcontroller or a digital signal processor (DSP), which are typically used for controller-oriented applications and numerically intensive digital signal processing, respectively. The processor 102 may have a hybrid microcontroller/DSP architecture which is able to handle applications which have both DSP- and microcontroller-based components. Such a processor may be used in, for example, a cellular phone which has a workload with a large DSP component for performing the processing required for the base-band channel and the speech codes, as well as a control-oriented component for managing aspects of the user interface and communication protocol stacks.

[0008] The processor core 105 may include a local, or Level 1 (L1), memory at the highest level of the memory hierarchy. The instructions and data in the L1 memory may be separated into a local instruction memory 120 and a

local data memory 125, but may share a common memory at the second and further levels of the system (L2 and lower).

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**[0010]** In addition to, or in place of, the L1 cache, the processor core 105 may include local (real) memory which may be programmed with information, such as L1 SRAM in the local instruction memory 120 and the local data memory 125. Unlike the L1 cache, the information in the L1 SRAM ~~(is)~~

**[may be]** addressable and does not depend on the task being performed, i.e., the information in the L1 SRAM is non-deterministic. Thus, accesses to L1 SRAM ~~do~~ **[may]** not entail cache miss penalties. Due to its proximity to the execution unit 130, the L1 SRAM ~~is~~ **[may be]** a relatively fast memory and may be used to store instructions and data for ~~critical~~ DSP applications ~~and functions~~, such as fast Fourier processing (FFP), correlation, and multiply-accumulate (MAC) ~~functions~~ **[instructions]**.

**[0011]** The execution unit 130 may read and write data to the local data memory 125 during execution of a program. The execution unit 130 may fetch instructions from the local instruction memory 120, but may not be able to write directly to the local instruction memory 120.

**[0012]** The system 100 may include a DMA (Direct Memory Access) controller 140. The DMA controller 140 is a specialized processor used to transfer information in or out of the local instruction memory 120 and local data memory 125 without intervention by the processor core 105. The DMA controller 140 ~~is~~ **[may be]** external to the processor core 105 and accesses local memory through the SBI 115. The DMA controller may read and write instructions to the local instruction memory 120 and read and write data to the local data memory 125.

**[0013]** The SBI 115 includes the fill bus 135 and the DMA bus 145. A fill bus interface 148 handles data transfers between the external memory 110 and a system port 150. A DMA bus interface 155 handles data transfers between the DMA controller 140 and a system DMA port 160. The processor core 105 may include an internal DMA interface 165 to handle transfers between the system DMA port 160 and the local memories 120 and 125.

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160 and the DMA bus interface 155. In the enhanced operating mode, the multiplexer may switch to the bridge 170 and ~~only~~ allow instructions and data to flow between the system port 150 and the system DMA port 160.

**[0016]** The multiplexer 175 may be controlled by the output of an AND gate 180. The inputs of the AND gate 180 ~~are~~ **[may be]** coupled to a control register 185 and an address decoder 190, respectively. The control register 185 may be a software programmable register which may be programmed to store a bridge-enable bit. The bridge-enable bit may be used to indicate whether the bridge is enabled or not, and hence whether the SBI 115 is in the normal or enhanced operation mode.

**[0017]** Figure 2 is a flowchart describing an operation 200 for enabling the processor core 105 to write the local instruction memory 120 and the local data memory 125 according to an embodiment[, **although the scope of the present invention is not limited in this respect**]. The processor core 105 may request an access to memory, e.g., a read or write access to the local instruction memory 120 (block 202). The SBI 115 receives the access request (block 204) and checks the status of the bridge-enable bit in the control register 185 (block 206). If the bridge-enable status is FALSE, i.e., the bridge-enable bit value



is zero, the processor 102 ~~is~~ **[may be]** in the normal operating mode, and the output of the AND gate 180 is FALSE. The multiplexer 175 blocks the information on the bridge 170 from being placed on the DMA bus 145, and the access request is sent to the external memory 110 (block 208).

**[0018]** The SBI 115 **[may]** also ~~checks~~ **[check]** the address of the target instruction or data with the address decoder 190 to determine if the address of the target to be accessed is within the address space assigned to the local memories 120 or 125 (block 210). If not, the output of the address decoder 140 is FALSE. Consequently, the output of the AND gate 180 is FALSE, and the access request ~~is~~ **[may be]** sent to the external memory 110 (block 208).

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**[0020]** The enhanced mode may be used for testing purposes. For example, if a test chip on which a processor under development does not include a DMA controller, the processor core 105 may be used to test the internal logic of the DMA bus interface in the SBI 115. The enhanced mode may also be used to insert breakpoints in the code in the local instruction memory 120 using the processor core 105. The breakpoints may be used to test different portions and functions of the code. The enhanced mode may also be used for development purposes, such as code patching to replace portions of code in the local instruction memory 120 using the processor core 105.

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**[0025]** A number of embodiments have been described. Nevertheless, it will be understood that various

modifications may be made without departing from the spirit and scope of the invention. For example, blocks in the flowchart may be skipped or performed out of order and still provide desirable results. Accordingly, other embodiments are within the scope of the following claims.